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Environmental Feasibility of Using Wetlands to Treat Runoff Pollution

L. E. Gadbois

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L. E. Gadbois

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Chemical and ecological characteristics of wetland types commonly occurring in and around Navy bases are reviewed. The natural wetland processes are examined from the perspective of their capacity to remediate nonpoint source pollution (NPSP). The ecological habitat value of wetlands is iterated, as are the habitat value changes resulting from pollution loading.

Five generic pollutant categories of NPSP are discussed: biochemical oxygen demand (BOD), nutrients, suspended particulates, heavy metals, and organics (petroleum, solvents, biocides). The ecological consequences of each pollutant category, the treatment principles for this pollutant category, and how wetlands can provide the necessary treatment conditions are discussed.

Choice of the correct wetland morphology is important for effective NPSP remediation. Guidelines for choosing an existing marsh or construction of a new marsh are provided.

A tidal salt marsh construction proposal is reviewed to determine the ecological validity, the expected remediation effectiveness, the side effects, and the legal requirements for the construction. The state of the science is still too immature to confidently predict the effectiveness of the marsh at this site. The indications are that insufficient residence time of the water pollutants will minimize the effectiveness. Also the varied and dynamic exchanges between the marsh and the adjacent water body will hamper efforts to quantitatively determine the level of remediation.

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SUMMARY

PROBLEM

Nonpoint source pollution (NPSP) (pollution originating from broadly dispersed activities), which is mostly contaminated stormwater runoff, is the major pollution source in most waterways. Discharge regulations (which will be binding to Naval facilities) to control NPSP are being implemented at the state and local levels. Most conventional wastewater treatment techniques would be very expensive to use for runoff. Lower cost techniques broadly applicable for Navy use are desired.

OBJECTIVE

Determine the effectiveness and general Naval applicability of using wetlands to mitigate runoff pollution.

APPROACH

This report has two main components: (1) a review of the state of the technology of wetland processes which provide pollution mitigation, and (2) the environmental feasibility of a proposed wetland construction for runoff mitigation use.

CONCLUSIONS

Wetlands can assimilate small loading rates of nutrients, biochemical oxygen demand (BOD), suspended solids, bacteria and degradable petroleum components, and provide valuable ecological habitat. Heavier loading will damage the marsh, reduce its habitat value, and exceed the assimilative capacity. Nondegradable contaminants (heavy metals, some organics) may be contained in the marsh. Over the short term this will ease the chronic exposure impact to adjacent recipient water, but over the long term a toxic waste dump may develop.

The morphology of the marsh has a major impact on the remediation effectiveness. Flushing, which sustains the marsh, also removes some pollutants before ample time for degradation has occurred.

There is a large knowledge gap to bridge before the ecological impact of a chemically characterized effluent added to a marsh can be confidently predicted.

Wetlands may be the best available technique for some runoff situations and be disastrous for others. Careful research will clarify those cases for which this technique is and is not appropriate. Wetlands will not be a universally applicable method for runoff remediation, but they should be the technique of choice for some situations.

RECOMMENDATIONS

Experimentation with this approach is encouraged. A strong emphasis should be placed on designing a marsh or using an existing marsh in such a way that the effectiveness of the remediation can be documented.

The chemical content of the outfall and the discharge characteristics should be examined to determine whether installation of a marsh is appropriate.

CONTENTS

TABLES

INTRODUCTION

Overland runoff entrains terrestrial material and is discharged into waterways. The biota in the receiving water may be dependent on the contents of the discharge for sustenance. They may also be harmed by the runoff and be intolerant to the changed habitat. If so they will be replaced by a different suite of biota.

Runoff impact on adjacent water is a natural process. Human activities have modified the physical and chemical character of the runoff. Often the quantity and velocity of discharge is increased, and the concentration of chemical loading changes. Human values are applied in judging the resultant changes in the receiving water. Humans view the water with recreational, commercial, and food interests, and changes which jeopardize these interests are undesired. Human impact on runoff often produces undesired effects.

Wetlands have always served to buffer upland and aquatic zones from deleterious effects of the other. Upland areas are protected from waves and currents by the buffering effect of the wetland. Aquatic systems are protected from pulses of contaminant-loaded runoff due to the water storage and filtering capacity of the wetland.

In the effort to reduce nonpoint source pollution (NPSP), it is sensible to turn to our natural ally — wetlands. This has historically been a wetland function. We now seek to harness this wetland system and put it to work treating NPSP.

Human impacted runoff is different, however, than that to which wetlands have historically been exposed. It contains whole categories of new (or heretofore in trace levels) chemicals: petroleum, herbicides, pesticides, solvents, heavy metals, plastics etc. We also produce terrific quantities of otherwise natural materials: biochemical oxygen demand (BOD), nutrients, suspended solids, etc. Thus, it is unwise to assume that wetlands will be able to treat runoff from human-impacted areas.

Despite the modern character of runoff, previous scientific research supports the intuitive idea that wetlands have some capacity to mitigate runoff pollution. The collective scientific knowledge is very limited as to the capacity of wetlands to deal with the variety and quantity of pollutants in human-influenced runoff. Even more limited are the data needed to judge whether wetlands can be used for routine mitigation of NPSP.

This report provides background scientific and ecological information to determine the environmental feasibility of building or using wetlands for treatment of storm runoff. Of specific interest is the general applicability of this technique to many Navy shore facilities.

Following this introduction, a general description of wetlands will be presented. Next will be a more indepth discussion of several of the wetland types common at Navy sites, which could be candidates for use by the Navy for discharge treatment. With this background information presented, the characteristics of a storm discharge will be presented. Each of these characteristics will then be discussed from the perspective of how wetlands interact with this component and, thereby, postulate the use of the wetland to mitigate the influence of this component of the discharge. Thus, a systematic review — by chemical group — of the influence of wetlands on typical stormwater discharge will be presented.

Last is a case study of a proposed wetlands construction for the purpose of NPS mitigation from a Naval base in Norfolk, Virginia (COMNAVBASE). Planning for this site would be typical for that used at other Navy sites in that the following steps need to be taken:

1. Chemical/biological/physical characterization of the discharge.

2. Identify whether a wetlands can mitigate the polluting components found in this discharge.

3. Determine the type of wetland to build that best mitigates the discharge pollution, given the environmental constraints that dictate which wetland types grow in this region.

4. Plan an environmental impact assessment to determine the impact of loss of the existing habitat versus the created habitat (wetland).

5. Obtain the necessary permits for the wetland construction.

6. Document the effectiveness of the wetland in mitigating the pollution. The ability to document remediation and the effectiveness of the wetland will be shown to be dependent on the construction design.

BACKGROUND

DEFINITION AND TYPES OF WETLANDS

Definition of Wetlands

"Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water.... Wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is predominantly undrained hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year" (Cowardin, Carter, Golet, & LaRoe, 1979).

"The term 'wetlands' means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." (33 CFR323.2(c); 1984).

Wetlands Classification — Older Terms

The following are some of the traditional terms used to describe different types of wetlands (Mitsch & Gosselink, 1986):

Swamp — Wetland dominated by trees or shrubs (U.S. definition). In Europe a forested fen (see below) could be called a swamp. In some areas, reed-grass-dominated wetlands are also called swamps.

Marsh -- A frequently or continually inundated wetland characterized by emergent herbaceous vegetation adapted to saturated soil conditions. In European terminology, a marsh has a mineral soil substrate and does not accumulate peat.

Bog — A peat-accumulating wetland that has no significant inflows or outflows and supports acidophilic mosses, particularly sphagnum.

Fen — A peat-accumulating wetland that receives some drainage from surrounding mineral soil and usually supports marshlike vegetation.

Peatland — A generic term of any wetland that accumulates partially decayed plant matter.

Mire — Synonymous with any peat-accumulating wetland (European definition).

Moor — Synonymous with peatland (European definition). A high moor is a raised bog, while a low moor is a peatland in a basin or depression that is not elevated above its perimeter.

Muskeg — Large expanses of peatlands or bogs, particularly used in Canada and Alaska.

Bottomland — Lowlands along streams and rivers, usually on alluvial floodplains that are periodically flooded. These are often forested and sometimes called bottomland hardwood forests.

Wet Prairie — Similar to a marsh.

Reedswamp — Marsh dominated by Phragmites (common reed); term used particularly in eastern Europe.

Wet Meadow — Grassland with waterlogged soil near the surface but without standing water for most of the year.

Slough — A swamp or shallow lake system in northern and midwestern United States. A slowly flowing shallow swamp or marsh in southeastern United States.

Pothole — Shallow marshlike ponds, particularly as found in the Dakotas.

Playa — Term used in southwestern United States for marshlike ponds similar to potholes, but with a different geologic origin.

Table 1 clarifies several of the types of wetlands.

Table 1. Comparison of terms used to describe similar inland nonforested freshwater wetlands.
(Table 3-1 in Mitsch & Gosselink, 1986)

North American Technology	← Marsh →← Bog →
European Terminology	← Swamp →← Marsh →← Fen →← Bog →
Characteristics	
Vegetation	← Reeds →← Grasses, Sedge →← Mosses →
Hydrology	← Rheotropic →← Ombrotrophic →
Soil	← Mineral →← Peat →
pH	← Roughly Neutral →← Acidic →
Trophic State	← Eurotrophic →← Mesotrophic →← Oligotrophic →

Wetlands Classification

The following alternate classification scheme is presented by Mitsch and Gosselink (1986). This scheme uses common terminology for ecosystems about which extensive research literature is available.

The seven major types of wetlands in the United States can be divided into two groups: coastal and inland.

Coastal Wetlands

These wetlands are influenced by tidally induced water elevation changes. In this tidal region, the salinity may range from that of the ocean to that of freshwater.

Tidal Salt Marshes — Found along protected coastlines in the middle and high latitudes. In the U.S., *Spartina* often dominates in the low intertidal zone and *Juncus* in the upper intertidal zone.

Tidal Freshwater Marshes — Found inland from the salt marshes, but close enough to receive tidal effects. They are dominated by grasses and by annual and perennial broadleaved aquatic plants. These are often a very highly productive ecosystem.

Mangrove Wetlands — Found along protected coastlines in the subtropical and tropical regions. These regions would be tidal salt marshes in higher latitudes. They occur in a wide range of salinity and tidal influences as do the tidal salt marshes.

Inland Wetlands

Frayer, Monahan, Bowden, and Graybill (1983) estimated that 95 percent of the wetlands in the lower 48 states were inland.

Inland Freshwater Marshes — Characterized by (1) emergent soft-stemmed aquatic plants, (2) a shallow water regime, and (3) generally shallow peat deposits. They occur in isolated basins, as fringes around lakes, and in sluggish streams and rivers.

Northern Peatlands — In the U.S., these systems are limited primarily to Wisconsin, Michigan, Minnesota, and the glaciated northeast, although similar peat deposits, called pocosins, are found on the coastal plain of the southeast. There are also mountaintop bogs in the Appalachian mountains. Peatlands are considered to be a late stage of the filling-in process.

Southern Deepwater Swamps — Woody wetlands of the southeastern U.S. with standing water most or all of the year. A variety of nutrient and hydrologic conditions may exist. Normally the dominant species are cypress and gum/tupelo.

Riparian Wetlands — Occur, often in extended tracts, along rivers and streams. They are periodically flooded but, otherwise, are dry for portions of the growing year. These ecosystems are generally considered to be more productive than the adjacent uplands due to the periodic inflow of nutrients, especially when flooding is seasonal rather than continuous.

WETLAND TYPES OF HIGH NAVAL INTEREST

As water treatment systems for storm runoff, three of the wetlands types may be of use to Navy applications. These are (1) freshwater marshes, (2) tidal freshwater marshes, and (3) tidal salt marshes. These wetland types will now be discussed in greater detail. Four aspects will be elaborated upon: (1) hydrology, (2) chemistry, (3) ecosystem structure, and (4) ecosystem function. Hydrology will be discussed because use of this system will require that hydrological criteria necessary for the system must be maintained. Chemistry will be discussed because the chemical activity (may or may not be biologically mediated) is responsible for the pollution remediation that will be desired from this system. Ecosystem structure is the basic component of the system. These components must be developed or maintained for proper ecosystem function. Lastly, ecosystem function will describe the habitat value and the functional processes. These processes will be responsible for the pollution remediation for which the wetland is used. This information is drawn largely from Mitsch and Gosselink, 1986

Freshwater Marshes — Hydrology

The character of all wetland types is determined by the flooding regime. Coastal areas tend to have a more stable water level due to oceanic influences. Inland marshes are controlled by precipitation and evaporation. Many of these marshes may dry down seasonally, but the plant species dominant there reflect the hydric conditions which occur during most of the year.

Generally, water sources other than direct precipitation are present. Some marshes are connected to the groundwater table and both fluctuate with and contribute to its level. Thus, precipitation collected in marshes can function to recharge the groundwater table.

Freshwater Marshes — Chemistry

Inland marshes generally are minerotrophic (i.e., the inflowing water has a high specific conductivity resulting from the presence of dissolved cations). The peat is saturated; as a result, the pH is close to neutral. Nutrients are plentiful relative to adjacent open water; nitrogen fixation is occurring; and productivity, litter decomposition, and turnover rates are high. Nutrient-loading, though high, is not as high as in tidal freshwater marshes. Dissolved inorganic phosphorus and nitrogen are the limiting nutrients. Concentrations vary seasonally from low in the summer, when plants take them up as quickly at they become available, to high in the winter, when plants are dormant but mineralization continues in the soil.

Freshwater Marshes — Ecosystem Structure

The vegetation is markedly similar worldwide. The dominant species vary from place to place, but the number of genera common to all the temperate freshwater marshes is remarkable. The common species do not occur randomly mixed in the marsh. Rather, each has a preferred zone.

The particular vegetation species found at a site are determined by many environmental factors. Nutrient availability determines to a large extent whether a wetland will support mosses or angiosperms (i.e., whether it is a bog or a marsh). Plant species change with latitude. Soil salts, even in low concentrations, determine species present.

As with other wetlands, inland marshes are detrital ecosystems. The primary consumers in these systems are rather poorly studied. Small decomposers (nematodes and enchytraeids) probably are of relatively more import than their counterparts in the adjacent terrestrial woodlands, where larger decomposers have a greater functional impact.

Mammals inhabit inland marshes. One mammal — the muskrat — can reproduce rapidly to population densities that can decimate a marsh.

Birds and particularly waterfowl are plentiful in all wetlands. This is probably due to the richness of the food and the diversity of habitats for nesting and resting.

Freshwater Marshes — Ecosystem Function

Primary productivity, generally, is high. Two common and highly productive monocotyledons are *Phragmites* and *Typha*. *Typha* productivity is highest early in the growing season, gradually decreasing through the season (Mitsch & Gosselink, 1986). *Phragmites* has a fairly constant efficiency throughout most of the growing season. Their conversion efficiency of from 4 to 7 percent of the photosynthetically active radiation is comparable to intensively cultivated crops, such as sugar beets, sugarcane, and corn. Herbivory in inland marshes, as with other wetlands, is fairly minor (Mitsch & Gosselink, 1986). Most production decomposes before it enters the detrital food chain. Decomposition for all wetland types varies due to the quality and refractivity of the plant material, temperature, availability of inorganic nutrients, and oxygen availability (which is largely controlled by the flooding regime).

Organic export is poorly understood. Experience with other ecosystems would indicate that export is largely influenced by water flow. The route for export from marshes with little water outflow is from organisms which feed in the marsh and then carry this organic energy away. Lakeside and riparian marshes, on the other hand, may export considerable organic material due to flushing (Mitsch & Gosselink, 1986).

Generalizing, nutrient budgets for freshwater marshes are useless because wetlands vary widely in many different ways. In many cases these wetlands function as nutrient traps. One very visible mechanism for nutrient storage is in vegetation biomass. This vegetation process shows great variability in the partitioning between above- and belowground components. More nitrogen and phosphorus is retained in the aboveground plant parts in mineral substrates (Whigham & Bayley, 1979). Biomass storage may be temporary. Storage occurs in the summer, and the nutrients are released when the plant shoots die in the fall. Nutrients detained in plant biomass may only comprise 20 percent of the total nutrients detained in the marsh (Sloey, Spangler, & Fetter, 1978). In the nutrient cycle, vegetation may also act as a pump by assimilating nutrients from the soil, transporting them to the shoots, and releasing them to the surroundings. Organic soils have large cation exchange capacities. This soil should be able to bind a large pulse of nutrients, but thereafter would be saturated. Only through denitrification or subsequent release of these nutrients would the assimilative capacity be restored.

Tidal Freshwater Marshes — Hydrology

These marshes are close enough to the ocean to experience tides yet are above the reach of oceanic salts. Such zones usually occur where precipitation is high or there is river water flowing to the ocean. These marshes are unique in that they receive the enriching effect of tidal pulsing without the stress of the oceanic salts.

Coastal marshes are of recent origin (Holocene). They lie in river valleys that were cut during Pleistocene periods of lowered sea level.

Tidal Freshwater Marshes — Chemistry

Generally, the sediments in these marshes are fairly high in organic content. The highest organic content is in the higher marsh, which is geologically older and more mature than the lower marsh. All but the thin surface layer of sediment is anaerobic and devoid of nitrate. During the plant dormancy of winter ammonium is present, but is almost completely assimilated in plants during the summer.

Tidal Freshwater Marshes — Ecosystem Structure

Vegetation varies with elevation in the marsh and latitude. Annuals grow along creek banks during the summer. In the fall, the tidal currents scour the creek banks clean of vegetation. Characteristic plants are found in the different regions of the marsh: the stream levee, the low marsh behind the levee, the high marsh, and streams and ponds within the marsh.

Seeds from all types of plants are found within the sections of the marsh but only certain species successfully germinate in each area. Flooding is one of the main controlling factors. Competition such as chemical inhibition and shading also are important. Not enough detailed studies in this area have been done to enable accurate predictions of which species will exist on each area of a tidal freshwater marsh.

Consumers are abundant. Benthic invertebrates are an important component in this predominantly detrital food web. The density and diversity of the benthic organisms are low compared with nontidal freshwater wetlands. This may be due to the lack of diverse bottom types. No species are found exclusively in tidal freshwater systems. Rather, those found appear to have a wide range (Diaz, 1977).

This is an important habitat for nektonic species, which use it for spawning, nursery zone, juvenile habitat, and year-round food and shelter. Most of these fish are freshwater, but some oligohaline or estuarine fish and shellfish and anadromous fish use this habitat.

These marshes support the largest and most diverse population of birds than any of the other wetland types. A major reason for this is the structural diversity of vegetation habitats in the marsh. Amphibians, reptiles and mammals also are frequent residents.

Tidal Freshwater Marshes — Ecosystem Function

Generally, productivity is high. The water motion induced by the tides stimulates production. The elevation gradient and the associated flushing and vegetation gradients result in three broad zones of primary production. The low marsh bordering tidal creeks is dominated by broad-leaved perennials and is characterized by low production, which peaks in the early growing season. Much of the production is stored in the belowground biomass; the turnover rate is high; the litter is swept from the marsh soon after it is formed; the soil is bare in winter; and erosion rates are high.

A portion of the high marsh is dominated by erect, tall species, such as perennial grasses, and has the highest productivity. Root-to-shoot ratios are near 1. Lower tidal energy and more refractory plant material cause accumulation of litter and little erosion.

In the remaining high marsh, which has a mixture of annuals, biomass peaks late in the growing season. Most production is aboveground (root:shoot < 1) and litter accumulates. Perennial roots with lower density than the rest of the high marsh would indicate higher erosion rates.

Little of the tidal freshwater marsh plant production is consumed directly. Most enters the detrital food chain by bacterial and fungal degradation and fragmentation by invertebrates.

Temperature is the primary factor determining the rate of litter decomposition. Additionally oxygenation, moisture content, and the kind of plant tissue involved affect the degradation rate. Anaerobic or dry environments have slow degradation rates. The marsh plants can be divided into two groups. The broad-leaved perennials generally contain high nitrogen concentrations in their litter and, thus, are decomposed much more readily. The high marsh grasses, the other major vegetation group, are very different. They contain little nitrogen and, thus, are a deficient food source, which results in their slow degradation.

Organic carbon is lost from the marsh due to respiration, flushing, conversion and storage as peat, conversion to methane, and export in the bodies of consumers. Flushing is prominent in the low marsh; peat formation is prominent in the high marsh. Methane is formed in anaerobic freshwater sediments where little sulfur is available for use as an electron accepter. Under these conditions, carbon dioxide can be reduced to methane.

The nutrient cycling and budgets in tidal freshwater marshes are similar to salt marshes in that they are fairly open systems with the capacity to act as long-term sinks, sources, or transformers of nutrients. Generally, nutrient input is inorganic which is reduced to organic forms that may be exported.

Tidal Salt Marshes – Hydrology

Salt marshes are dominated by rooted vegetation that is alternately inundated and dewatered due to influence of the tides. Often they appear from afar to be a vast monospecies of grass, yet in reality there is a zonation of plants, animals, and microbes. These plants face the daily stresses of salinity variations, alternate drying and submergence, and extreme daily temperature fluctuations.

Marsh development may be marine dominated or river dominated. Marine-dominated development requires sufficient shelter to ensure sedimentation and to protect excessive erosion. Adequately protected areas result from irregularities in the shoreline. River-dominated development results from river sediment discharge where the ocean is relatively quiescent. Generally, the marsh begins with freshwater species, but then the river changes course, the marsh becomes saline, and a species shift to a salt marsh occurs.

Marsh stability depends on the relative rates of two processes: sedimentation and coastal submergence. Sedimentation causes the marsh to grow upward and outward. Coastal submergence may result from geological drop in the coastline or from rising sea level. Oxidation in the marsh tends towards marsh stability. If a marsh subsides it is inundated more frequently and, thus, receives more sediment and stores more peat since the substrate becomes more anoxic and peat is degraded more slowly.

If, however, accretion is faster, the marsh gradually rises above the intertidal zone, is flooded less frequently, receives less sediment, and oxidizes more peat.

The upper and lower limits of the marsh are usually set by the tide range. The lower limit is set by the depth and duration of flooding, and by the mechanical effects of waves, sediment availability, and erosional forces. At least 2 or 3 days of continuous exposure are required during the seed germination period for seedling establishment (Mitsch & Gosselink, 1986). The upper marsh is flooded irregularly and has a minimum of at least 10 days of continuous exposure to the atmosphere, whereas the lower marsh is flooded nearly daily with never more than 9 continuous days of exposure (Mitsch & Gosselink, 1986).

Tidal creeks form in the marsh, especially in the low marsh. These creeks are conduits for material and energy transfer between the marsh and the adjacent water. The salinity in the tidal creek is similar to the adjacent water, and the water depth fluctuates with the tide. The microenvironment of the tidal creek supports different vegetation zones and food chains, which are important contributions to the adjacent estuary.

An additional feature of salt marshes are pannes — natural depressions that are intertidal and retain water even during low tide. Continuous standing water and elevated salinities from evaporation result in different vegetation than the surrounding areas. The habitat variation, shallow depth, and submerged vegetation of the panes are heavily used by migratory waterfowl (Mitsch & Gosselink, 1986).

Tidal Salt Marshes — Chemistry

If the *salinity in the marsh* is maintained below 5 ppt, the salt marsh vegetation is replaced with freshwater species. Salinity in the marsh soil depends on seven major factors (adapted from Mitsch & Gosselink, 1986):

1. Frequency of tidal inundation — Frequent flooding, as in the low marsh, results in more constant salinity than in the high marsh.
2. Rainfall — Frequent rain leaches the salt from the high marsh, whereas drought can result in elevated salinity in the high marsh.
3. Tidal creeks and drainage slope — Creeks and a steep slope speed drainage of the saline water at low tide, reducing soil salinity.
4. Soil texture — Silt and clay materials tend to retain more salt than does sand.
5. Vegetation — Vegetation reduces marsh surface evaporation, but causes evapotranspiration. The net effect, which is largely influenced by plant species and environmental setting, may increase or decrease total water loss. Vegetation also selectively takes up certain ions from the soil, changing the ion balance.
6. Depth of water table — The higher the water table, the less the fluctuations.
7. Fresh water inflow — Nitrogen is primarily the limiting macro nutrient (Valiela & Teal, 1974; Smart & Barko, 1980). In many systems, phosphorus is a limiting nutrient, but in salt marshes high concentrations accumulate.

Tidal Salt Marshes — Ecosystem Structure

Salt marshes are dominated by halophytic flowering plants, often dominated by one or a few species of grass. As with other marsh types, the species of vegetation are distributed according to the flooding regime.

There is contradictory evidence regarding the diversity of consumers in the salt marsh. High consumer diversity was noted by Davis and Gray (1966) and Niering and Warren (1977), whereas low diversity was noted by Teal (1962). The low diversity in the marsh may result from the low diversity of the dominant higher plants and the removal of much of the organic production through tidal flushing. The large population of waterfowl which use marshes is undisputed. Fish and shellfish populations are also high along the edge of the marsh. Thus, while the plant and animal diversity in the salt marsh is debatable, the extensive biological activity is obvious.

Tidal Salt Marshes — Ecosystem Function

Mitsch and Gosselink (1986) summarize the ecosystem function in the following manner:

1. Gross and net primary productivity are high in much of the salt marsh — almost as high as in subsidized agriculture. This high productivity is a result of subsidies in the form of tides, nutrient import, and abundance of water that offset the stresses of salinity, widely fluctuating temperatures, and alternate flooding and drying.

2. The salt marsh is a major producer of detritus for both the salt marsh system and the adjacent estuary. In some cases, detrital material exported from the marsh is more important to the estuary than is the phyto-plankton-based production in the estuary. Detritus export and the shelter found along marsh edges make salt marshes important as nursery areas for many commercially important fish and shellfish.

3. The grazing pathway is a minor energy flow in the salt marsh.

4. Leaves and stems of vegetation serve as surface areas for epiphytic algae and other epibiotic organisms. This enhances both the primary and secondary productivities of the marsh.

5. Detrital decomposition, the major pathway of energy use in the salt marsh, causes an increase in the protein content of the detritus and enhances its food value to consumers.

6. Salt marshes have been shown, at times, to be both sources and sinks of nutrients, particularly nitrogen.

WETLAND TYPES — CONCLUSIONS

Numerous wetland types have been presented; in fact, gradations of types in between those iterated are common. These variations result in a diverse set of habitat types. Generally, wetland productivity is high. This productive habitat results in wetlands serving a very important ecological role. As a transition zone between terrestrial and aquatic systems, they serve as habitats for animals from both, as well as buffering the two systems from harmful influences of the other system (e.g., aquatic waves and currents erode the land, and terrestrial sediment loading in runoff can "choke" aquatic plants and animals.

These past few pages have sketched the three types of wetlands that have potential for use by the Navy in NPSP remediation. This sketch was provided to build a basis for the ensuing discussions of specific aspects of wetlands' interaction with components of NPSP.

NPS RUNOFF CHARACTERISTICS

Runoff originates from all areas of a Naval facility and, thus, can contain pollutants originating from a diversity of activities. For purposes of discussion, these pollutants will be grouped into the following:

1. Biochemical Oxygen Demand (BOD) — This is generally an organic loading which causes reduction in oxygen level during degradation.
2. Nutrients — Namely, the macro nutrients of phosphorous and nitrogen needed for tissue syntheses by primary producers.
3. Suspended particulates — Organic and inorganic matter which reduces the clarity of the water.
4. Heavy metals — These may or may not be complexed as organic forms.
5. Organics — Petroleum products, solvents, and biocides (herbicides, pesticides, and fungicides).

Each of these five pollution categories will be expanded upon in the subsequent sections. The principles of techniques that mitigate each pollution type will be outlined. Then, the wetland will be examined to see if it provides the proper conditions to mitigate the pollutant.

BOD — The Problem

With few exceptions, aquatic life requires oxygen. The oxygen balance is determined by the balance between production, respiration (consumption), inflow, and exchange across the water-air interface. When demand exceeds supply, depressed oxygen levels result. Different species have widely differing oxygen level requirements. Generally, the more "desirable" species require the highest levels. As oxygen is reduced, these species are eliminated.

Presence of certain levels of reduced matter is natural and necessary. However, excessive levels become detrimental. An excess can arise as part of the natural cycle, or natural production can be stimulated by anthropogenic inputs (namely nutrients, see below) or by direct input of BOD material.

BOD material in runoff may or may not be anthropogenic and may or may not be detrimental. In general, however, harbors, bays, and estuaries around Navy facilities have restricted circulation and depressed oxygen levels. Under these conditions, BOD in runoff, whether anthropogenic or not, is detrimental.

BOD — General Solution

Treatment of BOD requires oxidation of the BOD-causing material. This occurs naturally by bacteria and other decomposers, provided nutrients are available, reducible matter is available (oxygen is generally used), and given enough time. The warmer the conditions, the less time needed.

To mitigate BOD in runoff, the flow of BOD matter must be delayed to allow bacteria to uptake the material and effect decomposition. The typical secondary treatment step in sewage treatment facilities is a good example of a technique to treat BOD. This technique consists of a large basin (like a swimming pool) with bubblers and a resident culture of bacteria. Sewage flows into the tank and is mixed with the bacteria. This bacterial/sewage "soup" is aerated for a few days. Nutrients are plentiful in sewage, and oxygen is provided by the aeration.

BOD — The Wetland Solution

For a wetland to be effective, the most difficult requirement is that adequate retention time be maintained to treat the dissolved fraction. Under nontidal flushing conditions this is an easy requirement, but with tidal flushing this is much harder to attain.

If runoff enters a high marsh with porous sediment, it can leach into the sediment, providing the necessary retention time. Oxygen or other oxidizers may be limited deeper in the sediment, so the capacity of this technique is rather limited. If the BOD concentration in the runoff is not high, however, this would be an excellent technique for mitigation.

If runoff enters the marsh in the high intertidal region, the BOD material must be restrained from flushing out with the diurnal ebb tide. There are only two water reservoirs in the marsh at low tide: pore water and depressions where water pools. Pore water exchange is relatively slow compared to the 12-hour tidal cycle, so depressions are the other viable option. These should be voluminous, plentiful, and positioned so that discharge goes from one to the next to obtain residence times of multiple tidal cycles. One way to envision this is a set of concentric rings radiating from the outfall. Each ring is a trough in the marsh which retains water. This technique requires that this troughed region of the marsh be in the high intertidal range, so that the whole area is not thoroughly flushed at each high tide.

If runoff enters the marsh at midtide height or lower, adequate retention time cannot be attained to mitigate dissolved BOD.

To summarize, BOD material is in a particulate or dissolved form. Removal of the particulate fraction can be attained simply by letting the water settle for a few hours. A marsh will do this effectively by dispersing the discharge over a broad area covered with vegetation stems which disrupt any water currents. The settleable particulates in this layer of calm water will then drop to the marsh surface. Dissolved and floating BOD material is harder to mitigate, and it is this fraction that requires the more elaborate designs, such as the retention troughs.

Nutrients — The Problem

Nutrients are the chemical elements necessary for life. They are typically divided into two categories: micro and macro nutrients. Micro nutrients are required by organisms in very trace amounts (such as zinc, iron, copper). In almost all environments, adequate amounts of these nutrients are available. This generalization of availability is especially true in the marine system due to the high concentration of dissolved minerals in saline water. Because they are seldom of concern, micro nutrients will not be discussed further in this report.

Macro nutrients on the other hand are required in large quantities. These are nitrogen and phosphorous. Often a limited amount of one or both of these limits further productivity in a system. Discharge of these nutrients in runoff to a system which is nutrient limited will initially increase the productivity, but the associated enhanced respiration and BOD-causing organic matter cause more severe drops in dissolved oxygen. Elimination of more of the desirable plants and animals results.

Nutrients — General Solution

In general, nutrients occur in dissolved form and toxic substances occur in particulate form (NOAA/EPA, 1989). Thus, methods dependent solely on pollutant settling will be ineffective.

Nutrients are used in primary production and bound into the biomass resulting from the production. Treatment then involves passing the nutrient water through a plant/algal community that is actively taking up the nutrients.

Nutrients — Wetland Solution

There is no consensus as to whether marshes have a net import or export of nutrients. What has been documented is that marshes convert inorganic nutrient forms into detritus which fuels the marsh detrital food web. Thus, nutrient forms which may otherwise fuel excessive algal blooms is converted into a form which fuels a "healthy" food web. The best estimate from existing research is that if nitrogen and phosphorus are added to a marsh, some of the phosphorus will be retained and some of the nitrogen will be converted into detritus. The net export of phosphorus should be less than input, and the export of nitrogen may approximately equal input, but some will be in detritus, which is a good food source.

Suspended Particulates — The Problem

Biologically inert material is also present in runoff but it does have an influence on the biota. This material clouds the water, thereby blocking necessary sunlight for photosynthesis. Particulate material may also settle on vegetation that blocks light. Particulate material can also overwhelm filter feeding organisms that ingest this material yet obtain no nutritive value.

Suspended Particulates — General Solution

Generally, particulates will sink or float out of the water column if given some time in calm water. Thus, treatment is easily achieved by diverting water into a settling basin, discharging from the middle of the water column, and periodically removing the bottom sediment and surface material.

Suspended Particulates — Wetland Solution

Wetlands approximate a settling basin in that flowing discharge water is dispersed and the velocity is greatly reduced. Particulates then can either settle onto the marsh surface, or the floating material can become trapped in the marsh vegetation web.

Heavy Metals — The Problem

Heavy metals are human and environmental biotoxins. They can be bioconcentrated in the food chain, which elevates potential exposure to some biota. The complexes in which they are incorporated may change but the metal atoms do not degrade.

Heavy Metals — General Solution

Metals tend to sorb onto organics and clay particles and settle along with these particles. Thus, a partial treatment for heavy metals is the same as shown for most pollution forms — settling time in a calm basin. This settling is enhanced by flocculation with material to which the metals can sorb. Expensive human-intensive tertiary treatments use such methods as chemical additions which flocculate and bind much of the otherwise nonsettling metals. Thus, there are two important criteria for a nonhuman-intensive treatment method to possess: (1) intervals with low water velocities to allow contaminated particulate matter to settle out of the water column, and (2) abundant binding sites for the metals to attach to.

Heavy Metals — Wetland Solution

Wetlands meet the two important criteria for heavy metal removal: low water velocities and abundant binding sites. Since marshes accrete sediment, if this sediment load is contaminated, the marsh will serve as a sink for metals.

During the growing season, plants take up metals which fall as litter as the plants die (e.g., Valiela, Banus, & Teal, 1974). This study noted that *Spartina alterniflora* concentrates metals to a high degree. These plants are then harvested by the tides, degenerated into detritus, and exported. This mechanism increases the possibility that heavy metals will enter the estuarine food web.

Wetlands, therefore, appear to have questionable value for treatment of metals in runoff. The total quantity reaching the adjacent open water will likely be reduced, but that which does reach the open water will likely be in a form more readily passed into the food chain. If metals are a major contaminant in the runoff, an alternate treatment method is advised.

Organics (Petroleum, Solvents, Biocides) — The Problem

Petroleum products, part of which is toxic, are a typical component in runoff. Routes for petroleum hydrocarbons to enter runoff are numerous. Oil, grease, gasoline, diesel fuel, etc., occur on roadways, parking lots, underground storage tanks, etc. Typically, and especially in dry climates, the petroleum has substantial time to physically and chemically interact with its environment before it becomes entrained in runoff during a storm. Often it is spilled or dripped on the ground surface across a broad area. This thin film at the ground surface can undergo extensive photo-oxidation, volatilization of the lighter fractions, and highly aerobic oxidation. Organic debris and mineral grains on the soil surface provide a variety of binding surfaces for this largely hydrophobic class of chemicals. Thus, the chemical ratios of weathered petroleum in runoff are substantially different than that in the original product. The water pollution loading, therefore, is higher in loading of refractile chemicals than the pure product components would indicate.

Prior to the onset of rain, the petroleum and degradation products are for the most part sorbed onto soil material. Rain causes a wetted surface and subsequent sheet flow. Three processes begin: (1) pollutants dissolve from the soil and pavement into the water, (2) water motion erodes and transports soil particle (with associated petroleum), and (3) immiscible droplets of product are entrained in the moving water.

Organic solvents may be present around industrial and commercial areas. Pesticides, herbicides, and fungicides are associated with domestic yards, agriculture, etc. These chemicals may be toxic and carcinogenic, and may cause cancer. Water solubility is variable.

Organics (Petroleum, Solvents, Biocides) — General Solution

Commercial wastewater treatment plants use chemical flocculants to induce precipitation of some of these compounds. Some degrade readily, but the rest comprise a group of chemicals which are very difficult to treat. Retention allows microbial biodegradation of the nonrefractile chemicals.

Petroleum products are hydrophobic. With high levels of contamination, little will dissolve. Most of it will float (giving the familiar colorful sheen on the water). Petroleum will also stick to particulate material, especially organic matter. Thus, the general approach to removing most of the material under heavy contamination is skimming the surface and providing organic material for the petroleum to stick to. This trapped material, and the dissolved portion also if retained for adequate time, will biologically degrade.

Organics (Petroleum, Solvents, Biocides) — Wetland Solution

For petroleum treatment purposes, a wetland can be viewed as a thick organic mat with a large surface area. Petroleum entering a marsh encounters extensive organic surfaces on which to bind. Once bound and detained, petroleum degrading bacteria have time to perform the degradation. The petroleum serves as a carbon energy source to the bacteria but is otherwise nutrient deficient. The bacteria generally obtain the other necessary nutrients from ions in solution in the marsh water.

Another factor which influences the degradation rate is temperature. Under winter conditions, degradation rates may be very slow and, thus, may not keep up with the petroleum input rates. In general, the rates at which most chemical reactions occur increase exponentially with rising temperature. Typically a 10°C increase can double or triple the rate of nearly all reactions, including biological phenomena. Winter remediation of the runoff is dependent on the marsh having enough surface storage sites to store the petroleum until warmer spring and summer temperatures arrive. Thus, as is intuitive for most of the other pollutants, the higher the pollution loading rate the larger the marsh needed to provide mitigation.

One poorly quantified and likely highly case-specific danger in loading a marsh with petroleum is that the petroleum adhering to the plant litter is being interjected directly into the detritus food chain. There are several key questions. First, what are the relative degradation rates of the petroleum and the leaf litter? If the petroleum is decomposed before the litter is used as detritus, adverse impacts are avoided. If not, the petroleum is ingested with the detritus. Another related key question is does the presence of a petroleum layer on the litter alter either the conversion rate into or the quality of the detritus? A third key question revolves around the summer-production winter-export cycle. In most temperate areas where the Navy has bases, marshes would be productive during the summer and not so during the winter. Also plant die-off and winter storms would cause most detrital export during the winter months. As outlined already, the winter litter will have the largest amount of nondegraded petroleum. As this litter is transported in the adjacent system, the petroleum may be physically dislodged or dissolved into this unsaturated, relatively petroleum-pristine area. Thus, an otherwise beneficial export of food chain material is the vehicle for transport of petroleum. Other remediation techniques would not have this complication.

Marsh vegetation will be harmed by a high concentration of herbicides. Runoff generally is dilute enough that this would not be a problem except in chemically intense agriculture.

No fungus species lives in brackish or salt water, so marshes in this regime would not be affected by fungicides.

Wetlands do provide a microbially rich environment that will remediate the biologically nonrefractory chemicals, but only if adequate retention time is insured. In tidal marshes with twice-daily flushing, this retention time will not be provided unless the marsh is hydrologically shaped so that inflowing runoff will oscillate back and forth many times before passing across the outer marsh edge.

WETLANDS CREATION – ENVIRONMENTAL FEASIBILITY

ECOLOGICAL VALIDITY

Will It Mitigate the Pollution?

Wetlands have always served as natural filters and water conservation devices. Through the accretion process, and because the majority of contaminants adsorb on particulate material, many contaminants are buried in the sediments, thus preventing the dispersal of pollutants. Soluble substances are converted into less mobile forms through incorporation into plant tissues. In addition, plants that dominate wetlands tolerate a wide variety of stresses and have a wide variety of opportunistic characteristics.

Reppert et al. (1979) list the following pollutants, which may be somewhat mitigated by the presence of wetlands:

1. Sedimentation
2. Organic matter and nutrients
3. Pesticides
4. Salinity and irrigation return flows
5. Heavy metals and radionuclides
6. Urban runoff
7. Livestock pollutants
8. Infiltrates of terrestrial waste products
9. Background emissions, air pollution, and other particulate matter
10. Industrial toxic wastes.

Accumulations of toxic pollutants (heavy metals, pesticides, and radionuclides) in streams and wetlands are linked primarily to natural sedimentation processes. The areas of sedimentation are sinks capable of concentrating many, if not all, of the nonbiodegradable pollutants. Studies have indicated that sediments and aquatic plants often possess concentrations of nonbiodegradable substances over three orders of magnitude higher than the mean concentrations in overlaying waters (Reppert et al., 1979).

Most pollutants are discharged in a pulse at the beginning of a storm event (Munoz & Garcia, 1987). For simulated rainfall on roadways, they found nearly an order of magnitude drop in concentration by the fifth minute. The relevance to remediation techniques is that the maximum treatment effectiveness should be for the first pulse of water.

A tidal wetland may provide differential treatment that may be positive or negative to that desired. If the discharge is above the water line, the desired pulse retention results. If the discharge is below the water line, an opposite effect of that desired results. If the initial discharge flows onto a drained marsh, a maximum amount will infiltrate the organic mat resulting in maximum detention for maximum remediation. When the mat becomes saturated following the initial runoff, the remainder flows over the surface to the water's edge. In a case where the outfall is below the water's edge, the initial most-contaminated pulse is pushed ahead by the remainder of the storm discharge. As the tide recedes, the water closest to the marsh edge (the contaminated pulse) is the first to drain from the marsh. The cleaner late-storm discharge has the highest retention time on the marsh.

If the marsh soil is saturated even at low tide (poorly drained or low porosity soil), the initial pulse will be washed from the marsh surface by the later storm discharge. Under these conditions, the marsh is providing a negative differential treatment.

Side Effects

Table 2 lists criteria for preliminary analysis of a wetland for its potential shoreline protection value (Reppert et al., 1979). These criteria represent generalizations, and each wetland under consideration must be evaluated on a site-specific basis.

Table 2. Preliminary analysis criteria.

1.	<u>Vegetation Characteristics</u>		<u>Value</u>
	A.	Type of Wetland Vegetation	
		Shrub and Arboreal Species	High
		e.g., mangrove (*Rhizophora* sp.)	
		willow (*Salix* sp.)	
		alder (*Alnus* sp.)	
		buttonbush (*Cephalanthus occidentalis*)	
		Nonwoody Emergents	Moderate
		e.g., intertidal grasses (*Spartina alterniflora*)	
		rushes (*Juncus* sp., *Eleocharis* sp.)	
		cattails (*Typha* sp.)	
		reeds (*Phragmites* sp.)	
		Submergents and Floating Leaved Species	Low
		e.g., seagrasses (*Thalassia testudinum*, *Zostera marina*)	
		pond weeds (*Potomogeton* sp., *Nuphar* sp.)	
	B.	Density of the Total Vegetation Community	
		Dense (coverage more than 80 percent)	High
		Semidense (coverage 50-80 percent)	Moderate
		Open (coverage 20-50 percent)	Low
2.	<u>Width of Wetland</u>		
	More than 200 yards		High
	100 to 200 yards		Moderate
	Less than 100 yards		Low
3.	<u>Fetch</u>		
	More than 5 miles		High
	1 to 5 miles Moderate		
	Less than 1 mile		Low

As mentioned in the wetland solution sections for the various toxic pollutants, the main harmful side effect of a contaminated wetland is input of contaminated food into the adjacent food web. Wetlands normally provide a detritus food base for the adjacent ecosystem. If the marsh plants assimilate the pollutants into their fibers without degradation, the result is direct interjection of the contaminants into the food web.

Verification of Mitigation Effectiveness

Gadbois (in press) outlines an evaluation approach to determine the effectiveness of the mitigation. The most difficult aspect for wetland effectiveness validation is determining the mass balance for exchanges of material between the marsh and the adjacent water body. This is due to the many forms in which pollutants may exist as they cross the marsh perimeter and the time scale of the interchange.

Pollutants may change chemically as they traverse the marsh. Thus, monitoring outflow for known chemicals in the inflow is not sufficient. Chemicals also change form within the marsh. Sorption, desorption, dissolution, chelating, flocculating, and uptake in plant material are examples of changes in physical characteristics. Third, storage in the marsh changes the time scales over which monitoring must take place. During quiescent weather and neap tides, flushing will be poor and pollutants will accumulate. During storms and spring tides, enhanced flushing will increase the pollution transfer rates.

PERMIT PROCESS

Environmental Assessment

In general terms, the environmental assessment (EA) must describe the existing habitat, evaluate its importance to its ecosystem, and postulate what the new habitat will be. If there is doubt about the new ecosystem structure or function, a monitoring program that will quantify the system changes should be included in the EA.

Whether an existing marsh is used for runoff treatment or a new marsh is built which displaced an existing habitat, the pre- and postactivity system must be quantified. This evaluation must both structurally and functionally describe the habitats. Also, the impact that this habitat has on adjacent areas and other biological resources which use this habitat must be evaluated.

Habitat value of a marsh is difficult to evaluate for three main reasons. First, there are organisms which live their entire lives within the marsh and, to a large extent, may have no real impact on areas outside of the marsh. Second, marshes have a complex chemical relationship with immediately adjacent areas; chemical forms change and retention times are variable. Third, marshes may impact areas or biota in distant habitats. For example, birds which normally reside elsewhere may use a marsh during their migration.

Legal Aspects

The U.S. Corps of Engineers has been required to issue permits for dredge and fill activities and modification of waterways since 1899, as mandated in section 10 of the Rivers and Harbors Act (commonly referred to as the Refuse Act). "The jurisdiction of this act was essentially based on the necessity of maintaining the navigability of the Nation's waterways." (Schneider, 1976). The Corps' jurisdiction was limited to navigable waters, which the Corps and the courts defined as below the mean high water level plus adjacent wetlands.

Several legislative enactments and judicial decisions led to expansion of the Corps' permitting review of factors other than navigability. One of these was a 1958 amendment to the Fish and Wildlife Coordination Act that elevated the value of fish and wildlife resources to receive equal consideration with other objectives, such as navigation. The Corps' policy of evaluating environmental effects during the permit review process began in 1967 as a result of these legal activities (Holmes, 1980).

The Nation's water quality program was totally revised by the Federal Water Pollution Control Act (FWPCA) in 1972, which triggered expansion of wetland protection to those adjacent to streams and lakes. This law stated that all pollutant discharges into waters are unlawful unless authorized by a permit. Nearly all the permitting and implementing authorities of the act were assigned to the Environmental Protection Agency (EPA). The major exception was section 404, which authorized the Corps to administer a separate permit program for dredge and fill material. The language of this new law extended the geographical extent of the Corps' authority to all waters of the United States, not just navigable waters below the mean high tide line as before.

Subsequent to the 1972 FWPCA, the Corps continued to use the traditional definition of navigable water rather than "water of the United States" to define the scope of their jurisdiction (Frasca, 1976). The effect of this limitation was the exclusion from the Corp's regulatory program of such lands as marshes, swamps, bogs, salt meadows, inland shallows, and many other coastal wetlands (Zinn & Copeland, 1982). A number of court cases during the next few years resulted in the Corps' revising its regulations, thereby encompassing these new jurisdictions. Alarmist press coverage resulted in numerous legislative bills to reduce the scope of the Corps' jurisdiction. In 1975, the Corps issued its revised regulations, which included definitions of the wetlands under their jurisdiction (Zinn & Copeland, 1982). Two years later, the Corps updated the regulations and used the term "waters of the United States" rather than "navigable waters."

The EPA has substantial responsibilities according to the 404 program. As outlined in 1982, these included the following (Zinn & Copeland, 1982):

- Works with the Corps in developing 404 (b) (1) guidelines.
- Has the ultimate authority to veto permits based on certain environmental criteria.
- Designates geographical areas and ecosystems where EPA will make final determinations on all permit proposals.

- Assists States in developing supervisory responsibilities where the responsibility for issuing permits in certain areas has been delegated from the Federal level.

- Persuant to a 1977 advisory opinion of the U.S. Attorney General, EPA can delineate the boundaries of navigable waters (that is, determine where the 404 program comes into play).

- EPA has the authority and is required to halt discharges where a section 404 permit has not been obtained. This is a common violation of the 404 program requirements.

The Fish and Wildlife Service and the National Marine Fisheries Service participate in the 404 permit process in accordance with their responsibilities under the Fish and Wildlife Coordination Act. This act requires that wildlife receive equal consideration in Federal water resource development activities. Generally, the Fish and Wildlife Service is involved in freshwater wetlands, and both services likely will be involved when coastal wetlands are affected.

The role of both services is advisory only. The Corps and the Fish and Wildlife Service work through a memorandum of understanding, dated 1967, which requires consultation and consideration of fish and wildlife resources in permit decisions. Subsequent legislative enactments, such as the National Environmental Policy Act (NEPA), and administrative pronouncements, such as the Executive Order on Protection of Wetlands (Executive Order 11990), have strengthened the coordination process and the role of these two advisory services.

Executive Order 11990 — Protection of Wetlands (Carter, 1977) was one in a series of executive orders issued by President James E. Carter, Jr., concerning protection and enhancement of the environment. This order requires that no Federal agencies support, assist, or finance new construction in wetlands unless there is no practicable alternative and the activity will use all feasible means of minimizing harm.

Carter (1979) also issued Executive Order 11988 — Floodplain Management. Since wetlands are generally floodplains, the Federal agencies have issued joint regulations to implement both orders (Zinn & Copeland, 1982).

Section 404 is the key Federal wetland management program. Permit applicants often complain of unnecessary, unreasonable, or unwise delays and decisions resulting from the implementation of section 404. The expanded geographical coverage has also been criticized. Delays, uncertainty, possible inconsistency of permit decisions, and the interagency review process inherent in the section 404 program have all been criticized.

These individual complaints result largely from two broader issues. First, there is no national wetland law. Second, the issue of whether wetlands should be regulated through a water quality approach or through land use controls has not been resolved. One result of an insufficient Federal stance on wetlands management has been increased efforts by the States and local governments to establish their own programs. In the following case study, the interaction of the Federal, State and local laws for the Commonwealth of Virginia will be outlined.

CASE STUDY – NORFOLK VIRGINIA

BACKGROUND

Construction of a marsh at the mouth of an existing storm drain has been proposed as a demonstration project for NPSP remediation. The chosen site is at COMNAVBASE Norfolk, Virginia, (latitude 36°57′2″N, longitude 76°19′0″W). The outfall is currently equipped with an oil-water separator. Storm runoff discharged from the outfall contains small immiscible globules of petroleum which cause a radially expanding iridescent sheen. Obviously, there is also dissolved petroleum present.

No detailed chemical data or bioassays for this outfall are currently available. Oil and grease and total suspended solids (TSS) (appendix A) have been monitored for several years with typical concentrations of 1 to 4 mg/l and 5 to 50 mg/l respectively (unpublished data, Commonwealth of Virginia State Water Control Board). An extensive chemical survey was conducted in May 1989 (unpublished data, Naval Civil Engineering Laboratory, Naval Ocean Systems Center). The samples, however, were subjected to poor handling that compromised the validity of the data. Generally, however, the data confirm the level and types of contaminants which would be predicted by examining the land use of the drainage basin.

Land use in the drainage basin indicates that petroleum and solids are not the only expected contaminates. Both semi-industrial and golf course runoff is present. Thus, this outfall provides a good test case for a marsh because several of the pollution categories discussed in this report are expected to be present. Whether analytically detectable levels of pollutants are present is unknown.

Appendix B contains ambient water quality data for a site upstream of the outfall (latitude 36°57′15″N, longitude 76°23′40″W). Nitrogen and phosphorus occur in medium concentrations according to the categories in NOAA/EPA (1989). The nutrient remediation for which wetlands are well noted will be beneficial at this site.

OUTFALL ELEVATION

The outfall is a 4-foot-diameter concrete pipe. Mean high tide is about three-fourths of the way up the opening. Thus, for a few hours each day water flows into the outfall. The significance of the low elevation (midtide height) of the base of the outfall is that when a marsh is constructed, the runoff input will be at midtide. For marsh surface to directly receive discharge from the outfall, it must be in the mid- and low-intertidal range. Areas of marsh surface above the discharge elevation will not receive a substantial loading. Thus, this area will contribute relatively little to the NPSP remediation.

Spartina alterniflora naturally grows in the upper two-thirds of the intertidal zone. It is the dominant native vegetation in this region of the United States. The low intertidal region is normally nonvegetated. With artificial planting, the intertidal range of the *Spartina* can be extended down slightly lower than its natural range

(Bob Lazor, USAE-WES, personal communication, June 19, 1989). Thus, with careful engineering much of the marsh surface receiving runoff can be vegetated, but this extended vegetation may have a tenuous long-term survivability because it is beyond its normal growing range.

The second drawback with the low discharge elevation is that the lower marsh elevation is the most flushed due to tides. Thus, residence time necessary for remediation may not be obtained.

IMPACT TO EXISTING HABITAT

The existing nonvegetated intertidal beach and the adjacent shallow subaqueous area will be completely replaced with a marsh. This complete replacement of the existing habitat does not imply a replacement of all the resident species. Many of the benthic invertebrates and algae species will exist in the marsh and, in fact, some will flourish in greater numbers. The changed habitat will support many new plant and animal species.

IMPACT TO ADJACENT HABITAT

Plant material produced in the marsh is important to the aquatic ecosystem because animal species use this material as a food source. However, few organisms can feed directly on plant stems, seeds, and roots. Most species are indirectly fed by marsh production. When the plants die, they are macerated by physical processes and attacked by bacteria and other micro-organisms to form detritus. Detritus, laden with the bacteria feeding on it, has greater nutritional value to higher animals than undecayed plant material (Dept. of the Interior, 1977). Small invertebrates feed on this material and are in turn fed upon by fish, shellfish, and other higher food-chain organisms.

In addition to food chain support, a second benefit of the marsh on adjacent areas is habitat value for mobile organisms which would use the marsh. Fish, crabs, larvae, and birds may all periodically leave the adjacent habitat to use the marsh. New species which require both a marsh habitat and adjacent open water or upland areas will be recruited to this new ecoregion.

The third major benefit of the marsh on adjacent zones is the trapping of runoff pollution within the marsh so the adjacent zones are less exposed.

LEGAL ASPECTS – PERMITS

A single, comp. ehensive permit application is required (U.S. Army Corps of Engineers, 1988). This permit is routed to and reviewed by the local, State and Federal regulatory agencies; namely, the Local Wetlands Board, the Virginia Marine Resources Commission, the Virginia State Water Control Board, the Tennessee Valley Authority, and the U.S. Army Corps of Engineers.

Although a single permit application is filed, separate permits are often required from each agency involved in the permit program. Authorizations or waivers must be obtained from each agency. The Virginia Marine Resources Commission (VMRC) serves as the central point of contact for the permit process.

Regulators retain the right to conduct site inspections before, during, and after a permit is issued. Additional descriptions of the proposed project may be requested.

The Corps drafts a public notice of the project and distributes this notice to inform the public and to solicit comments. All comments are considered by each agency. The other agencies may also publicize the project (at the applicant's expense) to solicit public comments.

Certain types of projects may meet the Corps' general permit criteria, which significantly streamline the permit processing requirements. The Corps will automatically check the permit application to see if it meets the criteria.

Property owners adjacent to the proposed project site and others who have asked to be mailed any public notice involving work in their particular area are furnished a copy of the public notice. Anyone may make a comment on a public notice.

At the close of the public notice comment period, public hearings may be held by the local, State, or Federal agencies. Most projects do not obtain enough public comment to require a public hearing. Attempts are made to resolve the issues in question informally. If a hearing is required, a 30-day public notice is advertised. A decision on the project will not be made at the hearing. A 10-day comment period will follow the hearing to allow for any additional facts or information to be submitted before the district engineer makes a final decision.

Projects affecting State and local wetlands will be heard by the appropriate Local Wetlands Board after a notice of public hearing has been advertised at least once a week for 2 consecutive weeks in a local newspaper. If no wetlands board has been established in the proposed project locality, a representative of VMRC will hold a public hearing. Decisions by a local wetlands board or VMRC must be made within 90 days of receipt of a completed application.

Protested projects that cannot be resolved, projects costing more than $10,000 involving encroachment upon or over State-owned subaqueous land, and all projects affecting State and local wetlands in localities without a wetlands board will be scheduled for public hearings by VMRC at its regularly scheduled monthly commission meetings. The commission will make a decision on the project at the meeting unless a decision for continuance is made.

Pending applications are discussed at a joint monthly processing meeting where representatives from all the involved State and Federal agencies assemble to discuss project impacts and possible alternatives. These meetings are designed to reduce the time lost through correspondence between agencies and duplication of requests to the applicant.

The subaqueous land upon which the wetlands will be built is Navy-owned. Since the State does not own this land, VMRC does not have direct jurisdiction (Jay Whitcomb, VMRC, personal communication, 19 June 1989). There is substantial intertidal beach under the jurisdiction of the local wetlands board and the Corps.

CONSTRUCTION ENGINEERING

In the discussion thus far, a recurrent idea, which has construction design implications, is the need for adequate pollutant retention time in the marsh. For pollutants in the settleable fraction, retention time is obtained by slow water velocities in the marsh which allow settling and subsequent decomposition. For pollutants which cling to organic material, binding sites are provided by the marsh vegetation where the material can then degrade. For dissolved pollutants, however, the runoff water mass itself must be detained adequately long for degradation or marsh uptake. Most marsh designs would provide adequate settling and organic binding sites, so the most difficult criterion for treatment purposes is water mass retention time.

The uncertain performance effectiveness and the need to determine the fate of pollutants in wetlands (Silverman, Stenstrom, & Fam, 1986) have construction implications. The marsh should be constructed and discharge applied in such a way that remediation can be documented. Too little is known about the fate and transport of pollutants in wetlands to a priori assume effective beneficial remediation.

CASE STUDY – CONCLUSIONS

1. Due to the low elevation of the discharge pipe, the marsh must be in the low- to midtide range to receive discharge water and, thus, partake in remediation.
2. The extensive tidal flushing resulting from the low elevation will result in minimal retention time of the discharge water.
3. Short retention time of the runoff will minimize the opportunity for the marsh system to trap and degrade pollutants.
4. A site where the discharge was at least above high tide would greatly increase the likelihood of mitigation.
5. Little chemical characterization of the effluent has been performed to see if it contains sufficient contamination to allow determination of the effectiveness of the marsh.
6. A substantial breakwater will be needed at this site due to the medium energy adjacent water body.
7. The marsh shape and the permeability of the outer breakwater should be constructed to maximize retention time of the runoff.
8. The most prolific marsh plants in this region in a mid- and lower intertidal range is *Spartina alterniflora*. This plant will tend to out-dominate all other macrophytes, resulting in a vast monoculture. This low diversity habitat reduces the faunal diversity. Intentional mounds and depressions may slightly interfere with runoff flow plan, but the subsequent vegetation diversity will elevate faunal species diversity and habitat richness.
9. Marsh plants are prolific. Seedlings planted in the right intertidal elevations with adequate breakwater protection can be expected to grow. Ability to establish a marsh at this site is not an issue.

10. Permit process for this site will be of about average difficulty with similiar projects attempted in the future. One major obstacle which would be typical for this type of project is encroachment on subaqueous State-owned land, which States are very adamant about protecting. In this particular case, the Navy already owns the subaqueous land. A track record of success at this site can be cited in future similiar permit applications, making them easier. Regulators will be more lenient with this permit because of the important research questions being addressed. When these questions are answered, future permit applications will not have this advantage.

11. The low elevation of the marsh with subsequent large tidal water exchange will be much harder to document remediation effectiveness than a site where the discharge was at a higher elevation.

REFERENCES

Carter, J. E., Jr. 1979. Executive Order 11988 — Floodplain Management. May 24, 1977; as amended by Executive Order 12148, July 20, 1979 — Federal Emergency Management, 44 FR 43239, July 24, 1979. in: 71:0271-0272, *Environmental Reporter*, The Bureau of National Affairs, Washington DC.

Carter, J. E., Jr. 1977. Executive Order 11990 — Protection of Wetlands. May 24, 1977. in: 71:0291-0292, *Environmental Reporter*, The Bureau of National Affairs, Washington DC.

Cowardin, L. M., V. Carter, F. C. Golet, E. T. LaRoe. 1979. *Classification of Wetlands and Deepwater Habitats of the United States*. U.S. Fish and Wildlife Service Pub. FWS/OBS-79/31, Washington, D.C. 103p.

Davis, L. V., and I. E. Gray. 1966. "Zonal and Seasonal Distribution of Insects in North Carolina Salt Marshes." *Ecol. Monogr.* Vol. 36:275-295.

Dept. of the Interior, U.S. Fish and Wildlife Service. 1977. *Coastal Marsh Productivity: A Bibliography*. U.S. Fish and Wildlife Service Pub. FWS/OBS 77/3, Gulf South Research Inst., Baton Rouge, LA 300p.

Diaz, R. J. 1977. *The Effects of Pollution on Benthic Communities of the Tidal James River, Virginia*. PhD Dissertation, Univ. of VA. 149p.

Frasca, J. M. 1976. "Federal Control of Wetlands: The Effectiveness of Corps' Regulation under [Section] 404 of the FWPCA." *Notre Dame Lawyer* Vol 51:509.

Frayer, W. E., T. J. Monahan, D. C. Bowden, and F. A. Graybill. 1983. *Status and Trends of Wetlands and Deepwater Habitat in the Conterminous United States, 1950s to 1970s*. Dept. of Forest and Wood Sciences, Colorado State Univ., Fort Collins, CO. 32p.

Gadbois, L. E. (In press). *Measuring the Effectiveness of Nonpoint Source Control Techniques for Aquatic Protection: A Summary Report*. NOSC TD #1682.

Holmes, B. H. 1980. "Federal Participation in Land Use Decision Making at the Water's Edge — Floodplains and Wetlands." *Natural Resources Lawyer* Vol. 13(2):386.

Mitsch, W. J., and J. G. Gosselink, 1986. *Wetlands*. Van Nostrand Reinhold Company Inc., New York, NY. 537p.

Munoz, A. H., and Garcia, E. J. H. 1987. "Pollutant Removal From Highway Surfaces in Madrid Using Irrigation Techniques." *The Science of the Total Environment* Vol. 59: 369-389.

Niering, W. A., and R. S. Warren. 1977. "Salt Marshes." in: *Coastal Ecosystem Management*. J. R. Clark (ed.). Wiley, New York. pp. 697-702.

NOAA/EPA (Heather Quinn et. al.). 1989. *Strategic Assessment of Near Coastal Waters: Susceptibility of East Coast Estuaries to Nutrient Discharges:*

Passamaquoddy Bay to Chesapeake Bay, Summary report. Strategic Assessment Branch, NOS/NOAA, Rockville MD. 38p.

Reppert, R. T. et. al. 1979. *Wetland Values: Concepts and Methods for Wetlands Evaluations*. U.S. Army Corps of Eng. Fort Belvoir, VA. 109p.

Schneider, W. F. 1976. "Commentaries — Federal Control over Wetland Areas: The Corps of Engineers Expands Its Jurisdiction." *Univ. of Florida Law Review*, Vol. 28(Spring):789

Silverman, G. S., Stenstrom, M. K., and Fam, S. 1986. "Best Management Practices for Controlling Oil and Grease in Urban Stormwater Runoff." *The Environmental Professional*, Vol. 8(4): 351-362.

Sloey, W. E., F. L. Spangler, and C. W. Fetter, Jr. 1978. "Management of Wetlands for Nutrient Assimilation. in: *Freshwater Wetlands: Ecological Processes and Management Potential*. R. E. Good, D. F. Whidham, R. L. Simpson (eds.). Academic Press, New York. pp. 321-340.

Smart, R. M., and J. W. Barko. 1980. "Nitrogen Nutrition and Salinity Tolerance of *Distichlis spicata* and *Spartina alterniflora*." *Ecology* Vol. 61:630-638.

Teal, J. M. 1962. "Energy Flow in the Salt Marsh Ecosystem of Georgia." *Ecology* Vol. 43:614-624.

U.S. Army Corp of Engineers. 1988. *Information Guide and Joint Permit Application*. U.S. Government Printing Office, Washington D.C. 59 pp.

Valiela, I., M. D. Banus, and J. M. Teal. 1974. "Response of Salt Marsh Bivalves to Enrichment with Metal-Containing Sewage Sludge and Retention of Lead, Zinc and Cadmium by Marsh Sediments." *Environmental Pollution* Vol. 7:149-157.

Valiela, I., and J. M. Teal. 1974. "Nutrient Limitation in Salt Marsh Vegetation," in: *Ecology of Halophytes*. R. J. Reimold, W. H. Queen (eds.). Academic Press, New York pp. 547-563.

Whigham, D. F., and S.E. Bayley. 1979. "Nutrient Dynamics in Freshwater Wetlands," in: *Wetland Function and Values: The State of Our Understanding*. P. E. Greeson, J. R. Clark, & J. E. Clark (eds.). Americal Water Resources Assoc. Mpls., MN pp. 468-478.

Zinn, J. A., and C. Copeland. 1982. *Wetland Management*. U.S. Government Printing Office, Washington, D.C. 149 p.

APPENDIX A. HISTORICAL CHEMICAL DISCHARGE DATA

(Obtained from the Commonwealth of Virginia State Water Control Board)

		Measured Parameter	
Monitoring Period	pH	TSS (mg/l)	Oil and Grease (mg/l)
January 1986	7.09	2	1
February 1986	7.27	10	15
March 1986	7.19	27	6
April 1986	6.92	9	2
May 1986	7.22	10	1
June 1986	7.3	23	2
July 1986	7.4	37	21
August 1986	6.95	9	4
September 1986	7.83	12	2
October 1986	8.14	29	9
December 1986	6.9	1	4
January 1987	7.8	46	3
February 1987	6.96	4	< 1
April 1987	6.9	25	3
May 1987	6.73	3	2
June 1987	6.8	9	3
July 1987	6.0	29	2
August 1987	8.8	46	< 1
September 1987	6.7	26	< 1
November 1987	5.82	40	3
December 1987	7.04	3	1
January 1988	7.01	18	7
February 1988	7.2	30	4
March 1988	7.2	8	4
May 1988	7.3	13	< 1
June 1988	7.1	< 1	11
July 1988	6.7	2	< 1
August 1988	6.7	< 6	< 1
September 1988	6.7	7	5
October 1988	6.7	5	< 1
November 1988	7.0	31	< 1
December 1988	6.9	16	< 1

APPENDIX B. AMBIENT WATER QUALITY

(From Chesapeake Bay Office, Virginia Water Control Board, 1987)

Station Location: Hampton Roads, Lower James River, Virginia

longitude 76°23'40", latitude 36°5'15"

STORET Code 2–JMS05.72

Parameter	Fall 1984	Wintr 1984	Sprg 1985	Sumr 1985	Fall 1985	Wintr 1985	Sprg 1986	Sumr 1986	Fall 1986
Depth	15.00	15.33	15.60	15.33	15.00	15.75	14.40	14.20	15.00
Temperature	21.65	7.19	18.42	24.96	19.83	6.31	14.75	25.06	19.43
Salinity	20.20	20.99	21.49	25.59	21.04	19.99	19.46	24.30	25.02
Secchi disk	N/A	1.31	1.36	1.34	1.30	1.13	0.87	1.00	1.80
pH	6.93	7.80	7.94	6.01	7.47	8.52	8.01	7.87	8.35
Probe D.O.	7.39	10.65	8.02	5.82	6.62	10.75	9.33	6.45	7.27
Winkler D.O.	7.45	10.36	7.74	6.04	6.99	10.89	8.86	6.15	6.85
Chlorophyll A	N/A	N/A	N/A	6.43	2.38	15.66	11.33	4.38	2.2
Nitrate	0.12	0.08	0.06	0.06	0.14	0.10	0.09	0.05	0.07
Nitrite	0.01	0.01	0.01	0.01	0.02	0.1	0.1	0.1	0.2
Ammonium	0.05	0.05	0.05	N/A	0.08	N/A	0.05	0.08	0.10
T.K.N.	N/A	0.52	0.47	0.42	0.50	0.50	0.53	0.49	0.45
Ortho Phos.	0.05	0.01	0.01	0.02	0.03	0.01	0.01	0.02	0.03
Dissolved P.	0.05	0.02	0.03	0.05	0.04	0.02	0.02	0.03	0.05
Total Phos.	0.08	0.05	0.05	0.07	0.06	0.06	0.04	0.05	0.06
Silicon	1.53	1.67	1.16	1.78	1.89	0.85	0.65	0.91	1.05
T.O.C.	5.50	7.13	6.20	4.33	5.30	5.75	5.40	5.50	4.90

Parameter	Units
Station depth	meters
Water temperature	Centigrade
Salinity at 25°C	mg/ml
Secchi disk transparency	meters
pH	standard units
Probe dissolved oxygen	mg/l
Winkler dissolved oxygen	mg/l
Chlorophyll A	ug/l
Nitrate, dissolved	mg/l as N
Nitrite, dissolved	mg/l as N
Ammonium, dissolved	mg/l as N
Total Kjeldahl nitrogen	mg/l as N
Orthophosphate, dissolved	mg/l as P
Total dissolved phosphorus	mg/l as P
Total Phosphorus	mg/l as P
Silicon, dissolved	mg/l as Si
Total organic carbon	mg/l as C